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Resistance to Inundation and Its Utilization by *Heptathela kimurai* (Araneae: Liphistiidae)

Narayoshi Kikuya[1]

菊屋奈良義[1]: キムラグモの洪水に対する耐性と それを利用した分布の拡大

Abstract The tolerance for flood damage of the liphistiid spider, *Heptathela kimurai*, was studied. The trap door of the spider has mechanical system in water sealing like the function of one-way valve. The result of experiment indicates that the spider is able to endure the inundation by the movement of "drifting, resting and swimming." The spiders of *Heptethela kimurai* must harness the inundation to spread their distribution.

Introduction

The liphistiid spider, *Heptathela kimurai* Kishida, is distributed in Kyushu, Japan, digging a nest hole under the ground surface of slope or cliff (Kikuya, 1980). The hole is made on hillside (Figs. 1–2), and a trap door is hunging at the entrance of the hole (Kikuya, 1982 a, b, 1993) (Figs. 3–4).

Usually, water flows down in a stream when it rains, and brings the danger of inundation on spider's nest holes. A few studies were carried out on the relation between the nest hole and the rainfall. Otsuka (1963) reported that the egg sacs were damaged by a spell of rainfall breaking into the spider's nest. On the other hand, Kikuya (1980) reported that the spiders of *Heptathela kimurai* preferably nested on both sides of rivers (Fig. 5). This fact gives rise to the question how did they go across the river, when the flood damaged the nest holes.

This paper reports on some results obtained from the experiment of imitated (artificial) rainfall under natural field condition, and describes that the spiders have a special ability against inundation.

Study Areas

1. Experiments with imitated rainfall in natural fields.

Experiments were done at three places in Oita Pref., Kyushu as follows. Of these, two were on the slope of inclination 37°～48° and the other one was in the flat field of inclination 2°. Seven to nine populations were respectively found there, and three or four populations nearest to the road were used for the experiments.

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[1] Oita Wildlife Institution Center, Higashi Yahata 6-3-1, Oita City, 870 Japan
(社)大分野生生物研究センター 〒870 大分県大分市東八幡 6-3-1

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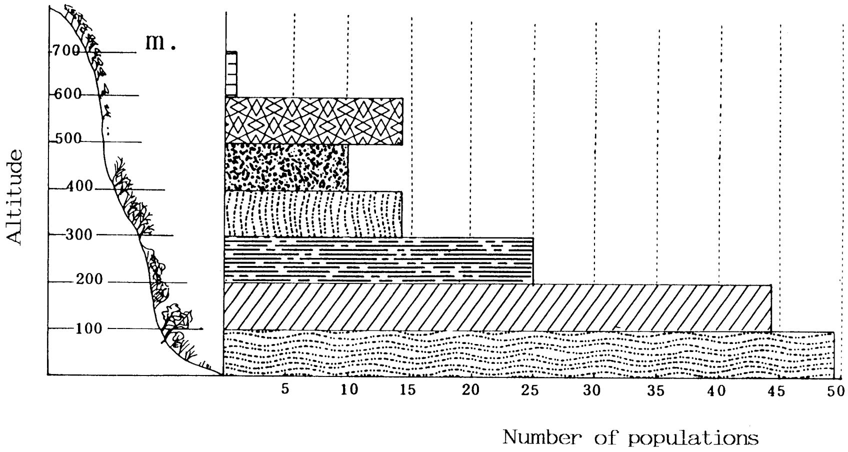


Fig. 1. Vertical distribution of *Heptathela kimurai* (after KIKUYA, 1980).

Angle of inclination	The number of nest holes		
	On natural slope	On artificial slope	Total
25°	1		1
30°	4		4
35°	2		2
40°	6	3	9
45°	5	9	14
50°	4	12	16
55°	3	5	8
60°	7	8	15
65°		1	1
70°	1		1
	33	38	71 71

Fig. 2. Frequency distribution of the spider's nest and inclination of soil surface (after KIKUYA, 1982).

In Figs. 6–7 the outline and views of the fields are shown.

1) Umedzu-goshi Pass (480 meters above the sea level) in Ume Town.

Eight populations were found at a wide and naked slope in a road side forest of *Pinus densiflora*. The trap doors were made of only soil or sand particles fastened by spider's spinning yarn.

2) Toh-shima Island (18 meters above the sea level) in Saiki City.

Seven populations were found at a slope covered with mosses along a narrow

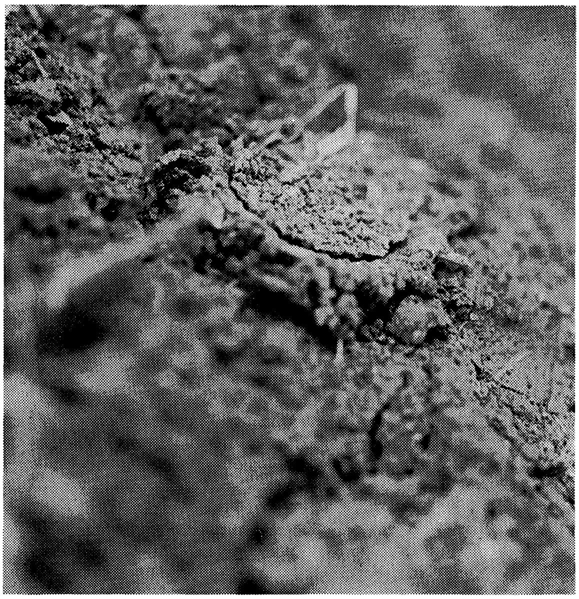


Fig. 3. A trap door of *Heptathela kimurai* (width about 10 mm).

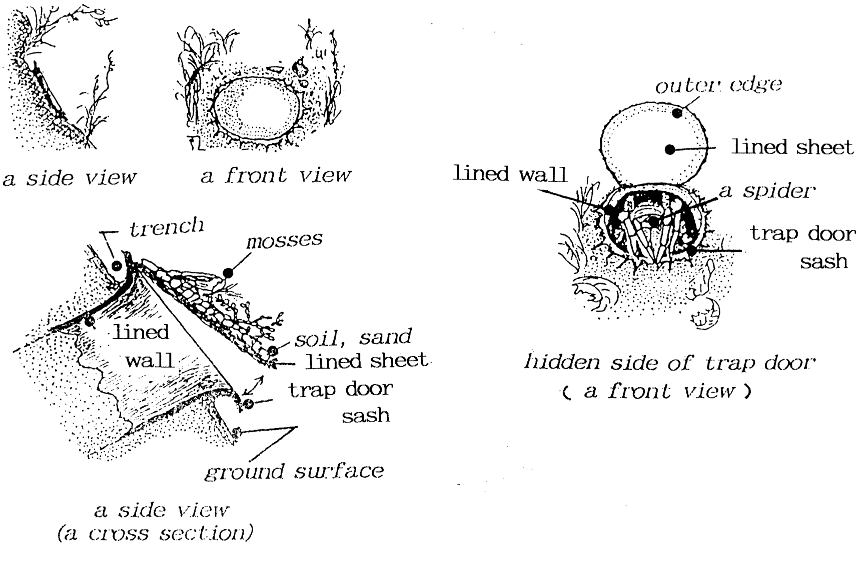


Fig. 4. Structure of the trap door of *Heptathela kimurai* (after Kikuya, 1993).

road in the forest of *Quercus phillyraeoides*. The trap doors used in the experiment were covered with mosses. Many crabs of *Chiromantes haematocheir* live around the trap doors in this experiment area.

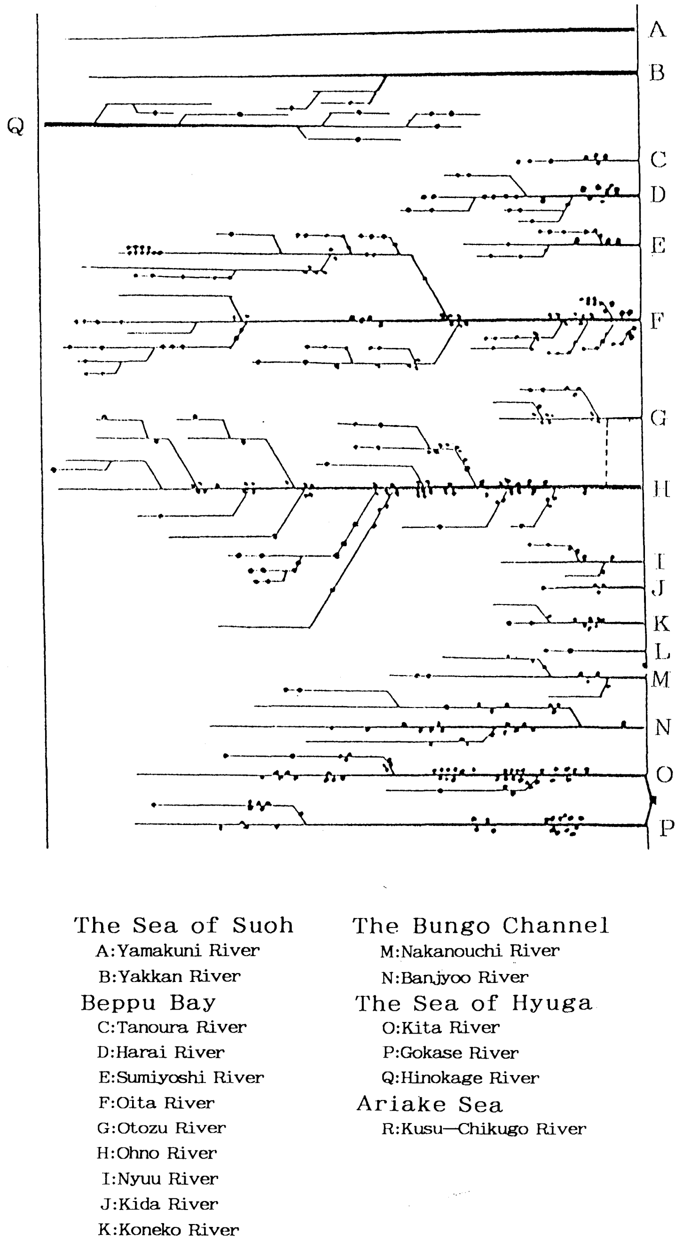


Fig. 5. Location of the nests of *Heptathela kimurai* along the rivers in northern Kyushu.

3) Ono-ue Hill (180 meters above the sea level) in Naokawa Village.

Nine populations were found on a flat and naked ground beside the forest of

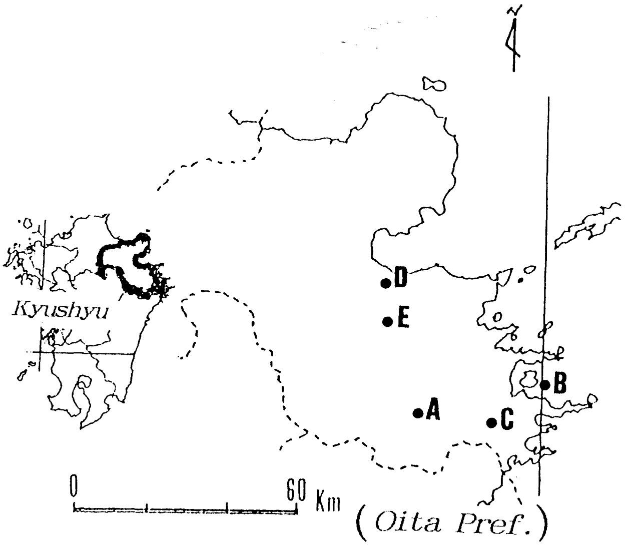
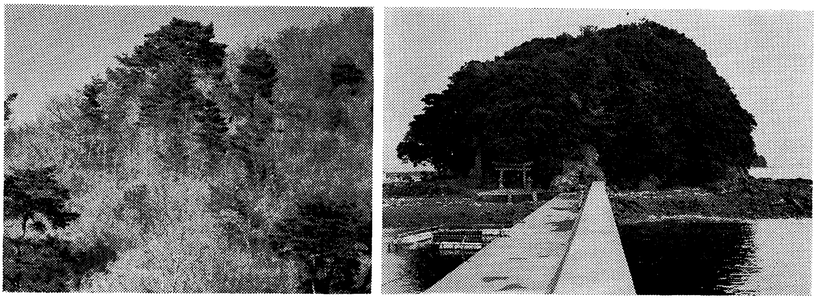
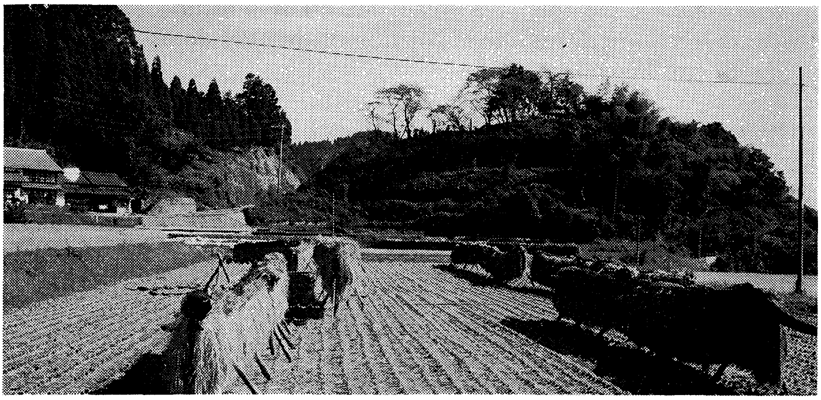


Fig. 6. Map showing the study areas.——A, Umedzu-goshi Pass; B, Toh-shima Island; C, Ono-ue Hill; D, Kozoh-zako Hill; E, Notsuharu Height where the spiders were collected. The vertical line in the right side: 132°N.



Umedzu-goshi Pass

Toh-shima Island



Ono-ue Hill

Fig. 7. Study sites.

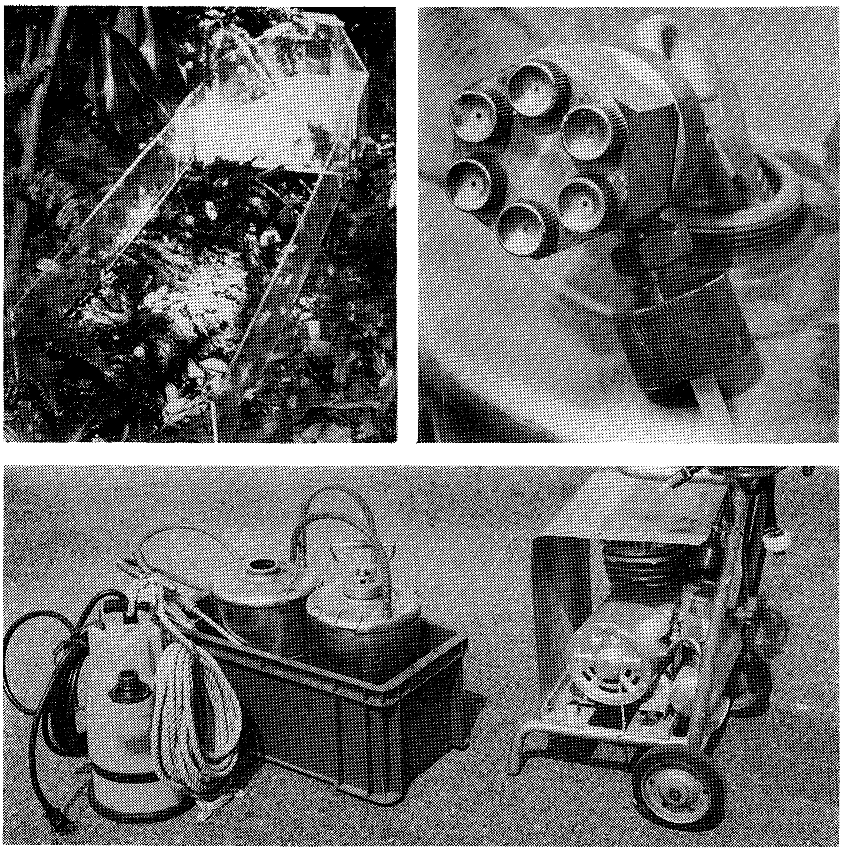


Fig. 8. The devices to make imitated rainfall. Divice for stream (top, left), spraying nozzle (top, right) and imitated rainfall kit (bottom).

Quercus acutissima on the top of a small hill. The direction of nest hole under ground were nearly vertical and the inclination of the trap doors was only 2°. The trap doors were not hunging.

2. Experiment for study on the endurances of the spiders against inundation.

The experiments were carried out in Kozoh-zako field in western part of Oita City. The devices used for the experiment are a water pot of 1.5 liters, a long tube of 180 meters, water sprayers of various sizes and a ditch of 50 meters long (Fig. 9). The spiders used in the experiment were collected at Notsuharu Town in Oita Pref.

Material and Method

1. Experiments with imitated rainfall in natural fields.

The trap doors used in the experiments were surrounded by plastic plates in each field. Imitated rainfall was sprayed from one meter above the ground surface by handy sprayer. The rainfall was given in three degrees: 2 liters/hour (as 10 mm rainfall), 10 liters/hour (as 50 mm rainfall), and 90 liters/hour (as 450 mm rainfall, "very heavy rain").

Fig. 8 shows the devices which were used for the experiments of imitated rainfall.

2. Experiment for study on the endurance of the spiders against inundation.

The spiders used in experiments were collected in the field in the forest of *Quercus glauca* which will be destroyed in a near future by the construction for a new road. The spiders were dropped down into the water in various conditions, and were observed for a certain period of time enough to complete the experiment.

1) Experiment in still water.

Each individual was dropped down into the still water which was prepared in a pot, and the action was observed for thirty minutes.

2) Experiment in circulating water.

Each individual was dropped down into the center of an eddy in circulating water, and the action was observed for thirty minutes.

3) Experiment in running water of stream.

Each individual was put on the passage point of the tube or ditch for the stream or flash water. In the artificial stream by city water, the water head pressure was adjusted to 2–3.7 kg/cm^2, and the velocity was set for 8–10 km/hour.

The devices used for study on endurance of spider against the flood are shown in Fig. 9.

Result

1. Experiment with imitated rainfall.

1) Umedzu-goshi Pass (480 meters above the sea level.).

The study fields were found in the forest of *Pinus densiflora*, and the ground surface of the fields was covered with Aso volcanic ashes. The trap doors of the spiders used in the experiment was located on the slope of inclination of 37 degrees.

The imitated rainfall was made by water sprayers with the tank capacities of 4 liters, 20 liters, and 200 liters. A scene of making artificial rainfall is shown in Fig. 10.

a) 10 millimeters precipitation (2 liters/hour).

About thirty minutes after the beginning of the imitated rainfall, the surface of trap doors and ground became only damp. After about one hour, the very faint and slow stream of water was observed. The speed of the stream was 0.5 meters per hour. In this condition, the outer surface and edge of the inner surface of the trap door were wet, and the frame of the entrance was wet, too. The trap door was shut tightly by the surface tension of water.

The stream was divided into two parallel ways along the trap door's edge. The imitated rainfall of 10 millimeters precipitation did not inundate the spider's nest hole, and the spider used it as usual.

b) 50 millimeters precipitation (10 liters/hour).

When the imitated rainfall was made, the surface of trap doors and ground became only damp after six minutes. After that, the stream of the rainfall begun

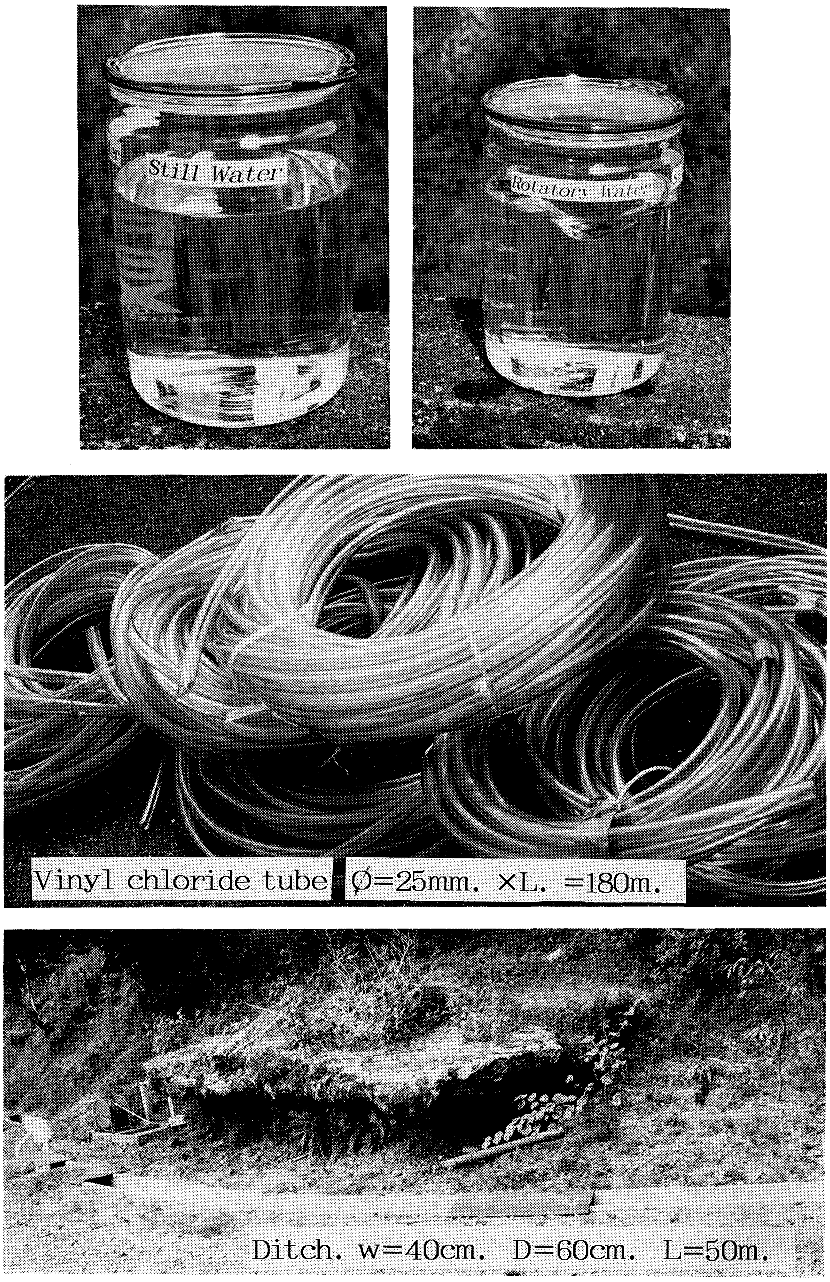

Still Water
Rotatory Water
Vinyl chloride tube Ø=25mm. ×L. =180m.
Ditch. w=40cm. D=60cm. L=50m.

Fig. 9. The devices for study on endurance of spider against the water.

to flow in the speed of 2.5 meters per hour. But the stream was divided into two parallel ways along the trap door's edge. The stream did not inundate the hole, too, and the spider had used the nest hole as usual, too,

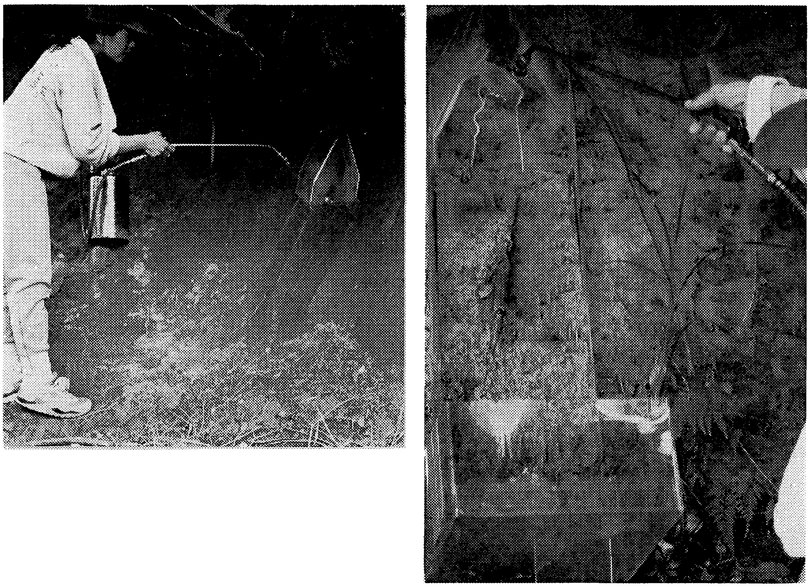


Fig. 10. Execution of the experiment with imitated rainfall.

c) 450 millimeters precipitation (90 liters/hour).

When the imitated rainfall was made, the stream had begun to flow down only after thirty-two seconds on the surface of trap doors and ground. The rainfall went down in a fast stream in the speed of 22.5 meters per hour and it drenched all the basin. The trap door was sealed up tightly by the weight of the stream itself, so the stream did not inundate the nest and the spider used the nest hole as usual. Figure 11 shows the phases of trap door's surface when they were get wet with rainfall, and Table 1 shows the relation between the volume of water and the condition of trap door.

2) Toh-shima Island (18 meters above the sea level).

The study fields were found in the forest of *Quercus phillyraeoides* on a small island that was covered with coastal lower plants. The slope used in the experiment had an inclination of 45 degrees. The trap doors of the spiders on this island were covered with mosses unlike those at Umedzu-goshi. But the result (shown in Table 1) was similar to that in Umedzu-goshi.

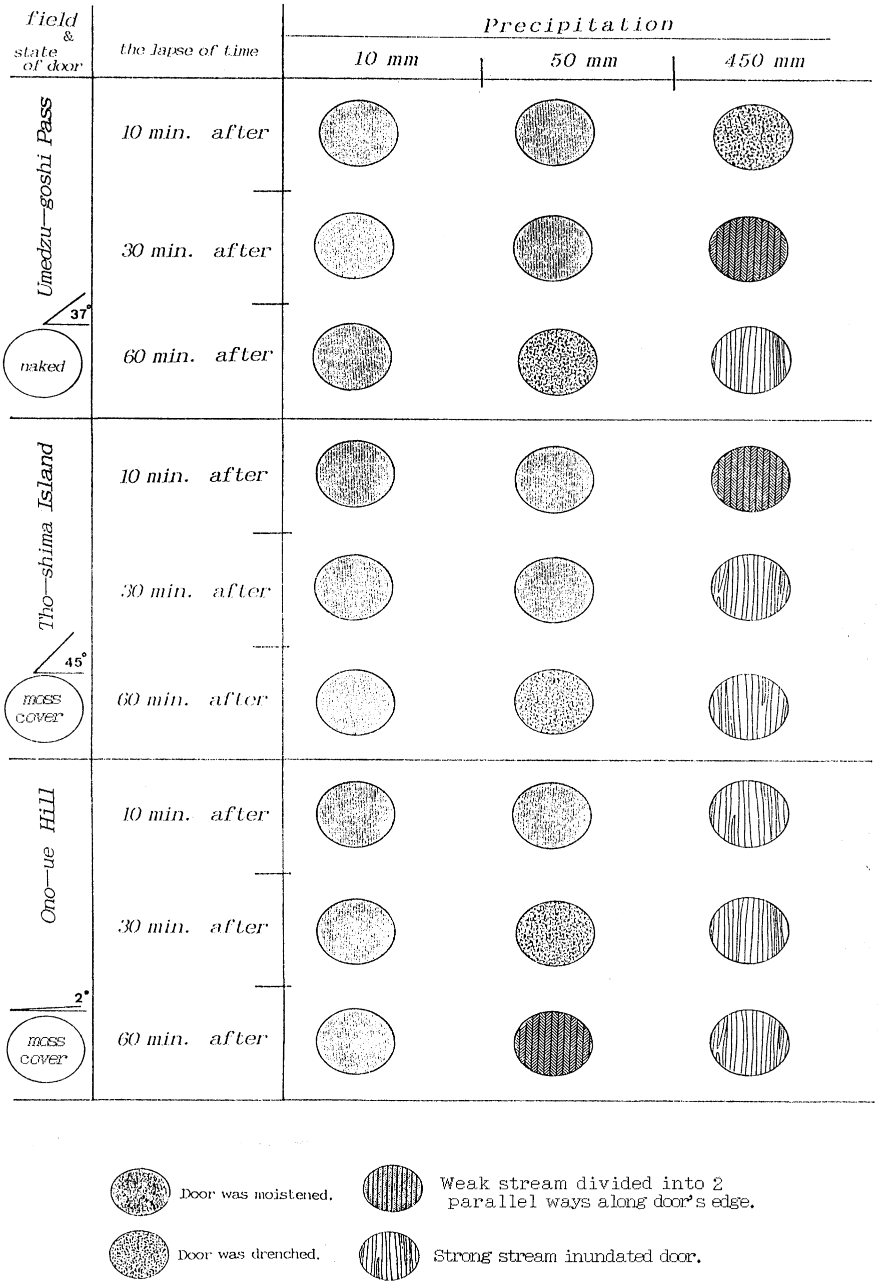
3) Ono-ue Hill (180 meters above the sea level).

The study field was located beside the forest of *Quercus acutissima* on the top of a small hill. The fields had an inclination of only 2 degrees, that is, almost on a flat surface, so the trap doors used in the experiment were made horizontally, being different from those on Umedzu-goshi Pass and Toh-shima Island. However, the trap doors were covered with mosses as in Toh-shima Island.

The result (shown in Table 1) was similar to that in Umedzu-goshi.

Conclusion. According to these results it can be safely said that the rainfall do not flood into spider's nest hole under natural conditions. The trap doors have mechanical water seal system as the function of one-way valve used in city-

Table 1. The state of door after the lapse of time when it rained on the field. (Result of experiment with imitated rainfall.)



Field & state of door	the lapse of time	Precipitation		
		10 mm	50 mm	450 mm
Umedzu–goshi Pass 37° naked	10 min. after	░	░	▒
	30 min. after	░	░	▩
	60 min. after	░	▒	▥
Tho–shima Island 45° moss cover	10 min. after	░	░	▩
	30 min. after	░	░	▥
	60 min. after	░	▒	▥
Ono–ue Hill 2° moss cover	10 min. after	░	░	▥
	30 min. after	░	▒	▥
	60 min. after	░	▩	▥

░ Door was moistened.

▩ Weak stream divided into 2 parallel ways along door's edge.

▒ Door was drenched.

▥ Strong stream inundated door.

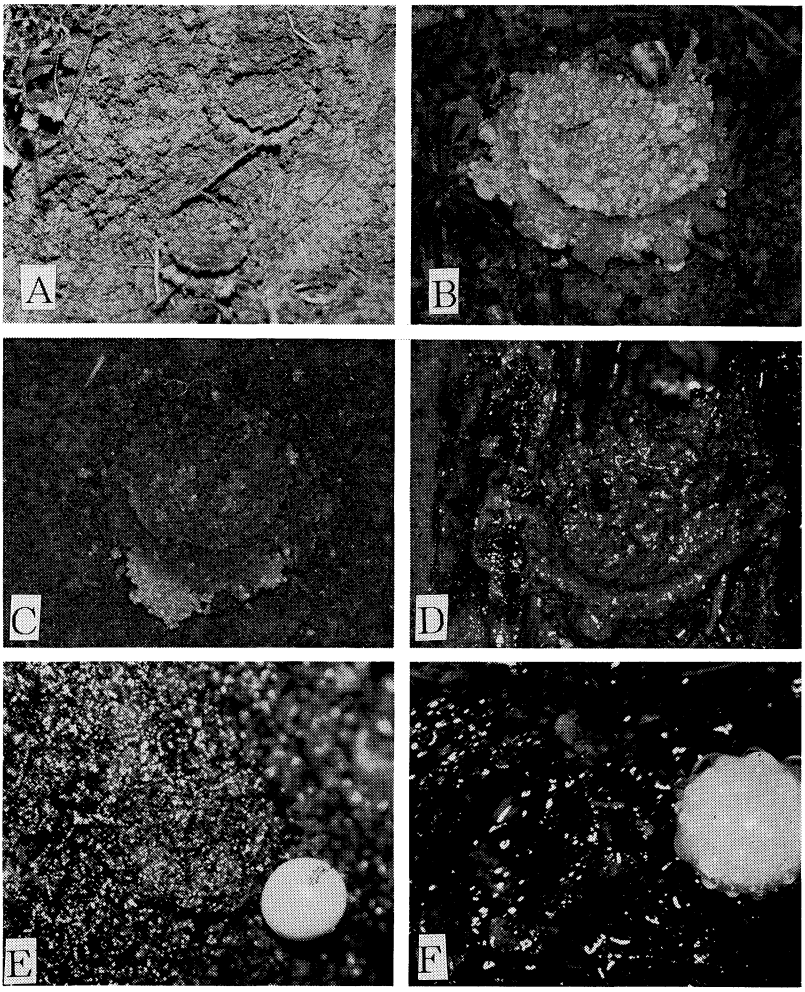


Fig. 11. The phases of trap door's surface when they were get wet with rainfall.——A, Before experiment; B, dried; C, moistened; D, drenched; E, slightly flooded; F, inundated.

water-line.

All individuals of *Heptathela kimurai* must have the ability of door making technique whenever they were born. Probably, they have instinctively a water guard system in their life, so the egg sacs were guarded against flood by the trap door with mechanical ability as one-way valve.

2. Experiment for study on the endurances of the spiders against the inundation.

1) Movement of spider in still water.

A female of spider *Heptathela kimurai* was dropped down into still water in a

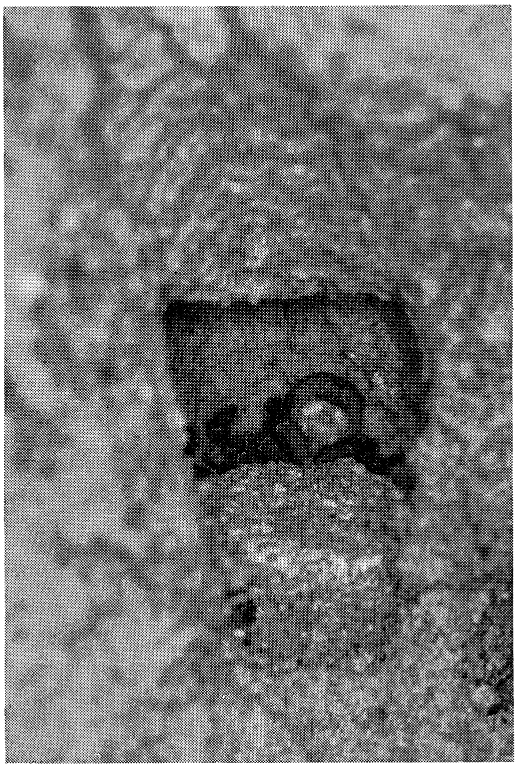


Fig. 12. A female spider (body length about 15 mm) and her egg sac, 15 minutes after the beginning of the experiment.

pot with 15 cm depth and 12 cm in diameter (Fig. 9), and was observed for thirty minutes.

Table 2 shows the result of this observation of the spider when she was in the still water. It classified into some aspects of the movement as follows:

A spider shrank her legs and rested in the water with drifting.

Sometimes the drifting spider stretched her legs and spread out in the water.

Sometimes the drifting spider swam in the water and tried to climb up on the pot wall.

The spider's body was fully parcelled by air bubble when she sank into the bottom.

The spider was never drowned.

The spider was still alive and in good health when the experiment was finished.

2) Movement of spider in circulated water.

A female spider of *Heptathela kimurai* was dropped down into circulated water in the same pot. The spider was drowned toward a center of an eddy bottom, after 2 minutes the spider floated on the water surface and was drifting slowly. After that the drifting spider showed the movement as same as in still water (Table 3).

Table 2. Spider's movement in still water, observed at each apointed time.

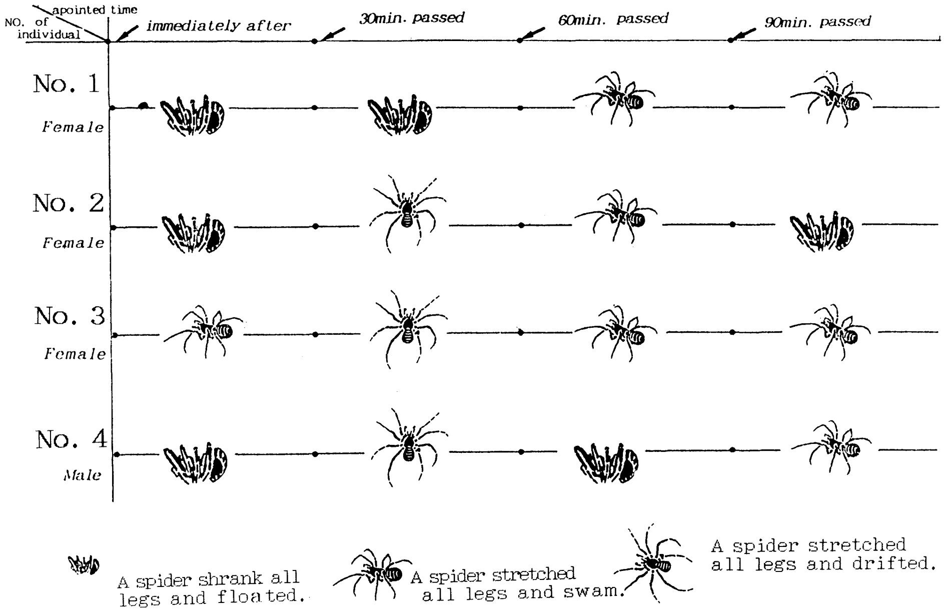
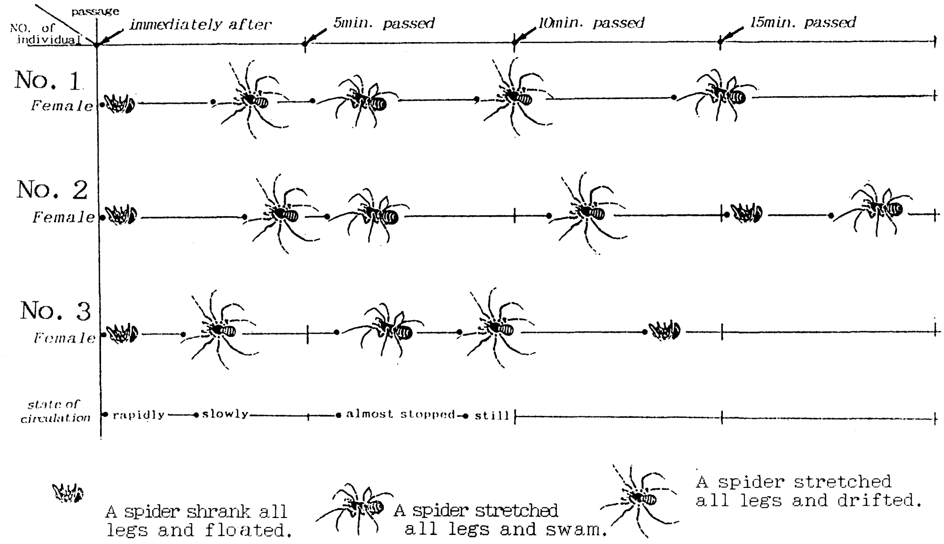


Table 3. Spider's movement in circulated water.



3) Movement of spider in running water of stream.

a) Stream in the vinyl chloride tube (180 m length, 2.5 cm in diameter) (Fig. 9).

Table 4. Spider's movement in flowing water in the tube.

NO. of individual \ Distance	start 20m. 40m. 60m. 80m. 100m. 120m. 140m. 160m. 180m.
No. 1 *female*	St.——Sw.——Sh.——St.——Sw.——Sh.——St.——Mc.——Tb.
No. 2 *female*	Sh.——St.——Sh.——St.——Sw.——St.——Mc.——St.——Tb.
No. 3 *male*	Mc.——Sw.——St.——Sh.——Mc.——Sh.——St.——Sw.——Sh. Tb.

Sh.	A spider shrank all legs and carried away.
St.	A spider stretched and moved all legs while carried away.
Mc.	A spider made every effort to cling on inner wall of the tube.
Sw.	A spider swam and floated down.
Tb.	A spider was taken back.

A female spider of *Heptathela kimurai* was put into the vinyl chloride tube. The spider began to walk in the tube. After one minute, city water (that had a water head of 3.7 kg/cm^2 and a velocity of 10 km/hour) had flashed into the tube. The spider was drifted in the stream and she could not swim against the stream. The movement of the spider was observed during the spider stayed in the tube. It was similar to that shown by the spider in still water (Table 4).

b) Stream in the ditch (50 m long, 40 cm wide, 60 cm in depth) (Fig. 9, bottom).

The ditch used in the experiment is called "U-type ditch." A female spider of *Heptathela kimurai* was put on the bottom of the ditch that was set along the lower side of a bamboo forest at Kozoh-zako field, in Oita City. The city water (a water head of 2.2 kg/cm^2 and a velocity of 8 km/hour) was flushed into the ditch. The spider did not swim against the stream and was drifted away, sometimes she caught a drifting leaf or side wall of the ditch.

The movement of the spider was observed during the stay of spider in stream. It was similar to that shown by the spider in still water (Table 5).

Conclusion. According to these results it can be concluded that the spider, *Heptathela kimurai*, has the ability of endurance for the water damage even in a strong stream of flashing water. The spider is able to endure by the action of "drifting, resting or swimming." The results show that the spider, *Heptathela kimurai*, should not be drowned by a flood.

Table 5. Spider's movement in streaming ditch.

No. of individual \ distance	start 10m. 20m. 30m. 40m. 50m.
No. 1 *Female*	Sh.——St.——Mc.——Sw.——Sh.——St.——Tb.
No. 2 *Male*	Mc.——St.——Sw.——Sh.——Mc.——Es. Tb.
No. 3 *Female*	Sh.——St.——Sw.——Sh.——CL.——Tb.

Sh. : A spider shrank all legs and carried away.
St. : A spider stretched and moved all legs while carried away.
Mc. : A spider made every effort to cling on inner wall of the tube.
Sw. : A spider swam and floated down.
CL. : A spider clung to drifting things and floated down.
Es. : A spider escaped from the stream to cling the wall of ditch.
Tb. : A spider was taken back.

Discussion

The spiders of *Heptathela kimurai* inhabit the forests in Oita Prefecture and are abundant on the slope or on the wall of the cliff. They had rich experience of so many landslides by heavy rains or locally torrential downpours. When the landslide broke out on the slope or the cliff, the nest holes of *Heptathela kimurai* were broken, too. Therefore, the spiders obtained the ability of dealing with water. The spiders of *Heptathela kimurai* are able to defend their egg sacs and themselves from heavy rain by mechanical sealing of the trap door. They are also able to defend themselves against the inundation by their movement, for example, to drift, to rest or to swim with shrinking and stretching their legs.

When the landslide is broken out on the slope or cliff, the spiders themselves and egg sacs are flushed out into the muddy water, and carried away to inundated river with muddy water. Then, the stream carries them to the lower part of the river. However, the stream in the river frequently clashes with the opposite shore especially in strong curvatures, so the spiders have many chances to reach the opposite shore. Still more, the stream in the river is often disordered in the sharp curve with many wreckages, on which some drifting spiders are able to cling to reach the opposite shore.

The inundation can carry the spiders to opposite shore. Thus, *Heptathela kimurai* should be distributed on both sides of a river.

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摘要

河川の両岸に分布するキムラグモ (*Heptathela kimurai*) の個体群に着目し，このクモがどのような方法で河川を横切って分布を拡げたのか，その渡河方法や水との関係を知るために野外実験を行った．実験は，キムラグモの住居巣のトラップドアと雨水との関係，及び，個体の耐水性，の2種類にわけて実施された．人工降雨実験の結果，トラップドアは，逆流防止弁と同じ防水機能を備えていて，雨水が住居巣を浸水することは，自然条件では否定的であることが判明した．また静水や流動水中に落としたクモの行動を観察したところ，このクモは水中では，浮遊，休止，泳動の3種類の動作を使いわけて，水没死しないことがたしかめられた．以上の研究結果からキムラグモが豪雨による崖崩れなどを原因として，濁流の河川に流入し，河川曲折部の乱流などを利用して，対岸に渡ったり，下流域に流されたりしながら分布を拡大してきた可能性を認めた．

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